FIRE BEHAVIOR MODELING AND THE PREDICTION OF WILDLAND CONFLAGRATION

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Modeling fire behavior, that is, developing a set of mathematical expressions that will calculate the rate of spread, fire intensity, flame length, etc., of wildland fires is an emerging science. Models, or systems composed of a set of models, have been used by land managers to assess fire problems and develop fire management plans for several years. Fires in the Greater Yellowstone Area in 1988 provided a severe test of these methods. A review of the fire assessment techniques and how they were used in Yellowstone this year shows that there is considerable research yet to be done, especially during extreme fire conditions. Data from the fires should aid considerably in developing methods for predicting severe fire behavior.

Fire Research Background

Wildland fires can take on many forms, depending on the way they are moving in relation to the wind or the stratum of fuel in which they are burning. The two important types are surface fires and crown fires. Surface fires burn in fuels that are contiguous with the ground, such as grasses, shrubs, dead needle litter, or other debris that has fallen from the trees. Crown fires spread through the tree crowns. Crown fires may be supported by a surface fire beneath the overstory or spread independently. Over 95 percent of all fires are of the surface fire type and it is at this stage of development that fire control forces have a chance of controlling them. Moving crown fires are virtually impossible to stop. Fortunately, less than 5 percent of all fires become crown fires. This, however, was not the case in Yellowstone during the summer of '88. Because of the combination of conditions, the extremely dry fuel, continuous stands of overmature lodgepole, and the strong winds, crown fires were very common in the summer of '88.

Up to now, most of the work on fire behavior prediction in this country has been directed at developing techniques for predicting the spread of surface fires. There are several reasons for this.

(1) Surface fires are the most common type of fire.
(2) A model of surface fire behavior was needed for developing the National Fire Danger Rating System.
(3) Experimental facilities were available for detailed studies of surface fire behavior.

Research on crown fires is much more difficult and studies in this area have been more sporadic, suffering not only from the complexity but also from lack of crown fire data, budget cuts, and loss of personnel. The research described here has been done at the Intermountain Fire Sciences Laboratory in Missoula, Montana, part of the Intermountain Forest and Range Experiment Station. It was built in 1960 and contains facilities for conducting experiments under

controlled atmospheric conditions. A large burning chamber, 60 feet high and 44 feet square, in which the temperature and humidity can be carefully controlled, is used for conducting fire experiments in the absence of wind. Experimental fires may also be examined in either of two wind tunnels where, in addition to the temperature and humidity, windspeed and wind direction are also controlled. Many fires have been tested in these facilities to collect data for use in developing mathematical models of fire behavior. In addition to the fire models, considerable research has been done to characterize the physical and chemical properties of forest fuels. The response of these fuels to changes in temperature and humidity, and the effect of slope on rate of spread have all been studied. Combined with data from fires in the field needed to show perimeter development, a set of mathematical models that describe fuels, weather, topography, and fire behavior has been integrated into methods for assessing fire conditions. Fire prediction systems developed from this research are described below.

Predicting Fire Behavior

There are three ways that fire assessments can be made. One is with the National Fire Danger Rating System (NFDRS); another is with the Fire Behavior Prediction System (FBPS); and the third is the use of personal experience gained on fires.

The National Fire Danger Rating System (NFDRS) is designed for broad-scale assessment of weather on forest fuel conditions. Its primary purpose is as a pre-fire planning tool. The indexes and components provide information about the fuel moisture of various size classes as well as the live and dead components of the forest, the effect of wind and slope, and types of fuels. This information is processed by the models in computers to produce indices such as the Probability of Ignition, the Energy Release Component, and the Burning Index. The Energy Release Component is designed to indicate drought conditions, and how severe the fires can be expected to be as a result of lack of fuel moisture. The Burning Index which combines the effect of fuel moisture with the effect of wind, gives an overall assessment of expected fire behavior. The NFDRS relies on inputs from fire weather stations on a daily basis. The data from each station is processed to indicate the conditions at that site. The system has recently been broadened to combine information from various sites and assess the behavior over large geographical areas. Areas as large as half of a state or two or three smaller states are combined to produce maps of the entire country that show the relative fire severity across the country.

A primary attribute of the National Fire Danger Rating System is that all of the data that is taken is archived at a central computer. These data can be recalled to compare existing fire conditions with conditions from previous years. Comparisons of current conditions with previous conditions is an excellent tool for developing fire management plans and setting decision criteria. The problem, of course, is that the Fire Danger Rating System does not have a capability for forecasting fire conditions. It can only assess what has happened up to that time.

Whereas the National Fire Danger Rating System (NFDRS) is used for broad area assessments of fire, the Fire Behavior Prediction System (FBPS) is designed to be site-specific. Attention can be directed to a drainage or a section of a

fire and, given the weather, fuels, topography, and a forecast of the weather, estimates can be made of how the fire is likely to burn under these conditions. Fire growth in surface fuels can be transferred to a map to help the fire suppression team develop suppression strategies and brief fire crews on expected fire behavior. The fire behavior analyst on each team is trained to make these assessments. The FBPS is available in several forms: nomograms that can be carried in the field and solved with a pencil and ruler, a computer program called BEHAVE, and pre-programmed computer chips for handheld calculators that the fire behavior analysts can take to the field. The fire behavior analyst is the key person in the assessment of wildfires. They must attend 2 weeks of rigorous classroom training after which they are apprenticed in the field with experienced fire behavior officers before becoming qualified to work with a fire suppression team.

Personal fire experience is the third method of estimating fire behavior and this was called into play at West Yellowstone in late July by six fire behavior specialists who were requested to estimate how large the fires in the Park would become. This was an extremely difficult task because there were nine major fires burning in the Park at that time. Some were being suppressed and some were not. Because of the remoteness of some of the fires, it was not possible to reach them, or even see them from aircraft because of the large amount of smoke covering the Park. Fires on the southwest side were burning in relatively flat, high elevation areas; those around the north and east rims were burning in steep mountainous terrain. It was impossible to do the close-in assessment of conditions that normally is done by fire behavior analysts. Fortunately, the Park Service had mapped the entire Park by vegetation types related to their burning characteristics. These included five stages of development and decay of the lodgepole pine forests as well as the spruce/fir, Douglas-fir, and alpine types. Experience from several previous years indicated the burning characteristics of these types.

The fuel maps were also being used by fire behavior analysts working in the Park this summer. They had had a week or two of experience in assessing the behavior of fire in these types. This background of experience was used to develop a plan for estimating fire behavior using the fuel type maps and a forecast of expected weather conditions for the remainder of the summer. The Area Command staff asked for a "worst-case" projection of the fire behavior and, after considerable discussion, we decided that we really didn't know how to do a "worst-case" assessment, but could do a "most probable" growth estimate. We did this by constructing a matrix between the fuel types and seven classifications of possible weather, ranging from a damp fire-stopping precipitation event through a hot and dry condition with severe wind. Possible weather information was obtained from two sources: one was a climatological review from the NFDRS Fire Weather Library, and the other was a long-range forecast provided by the National Weather Service. For each fuel type and the weather events that would carry fire, a matrix of the probable rate of spread, either due to surface burning, spotting or crowning, was developed.

The matrix showed that the only significant spread occurred in the LP-3 and LP-4 types, the older more decadent lodgepole pine types, burning on hot and dry days with strong winds. In the worst fuel type (the LP-4) on a strong-wind day, we estimated that the fires could burn up to 4 miles a day. Using the matrix and the fuel maps, we projected the growth of all of the fires to mid-August and to the end of August. We did not attempt to estimate fire

growth in September. These projections were given to the Area Commanders and the Park Superintendent on August 2. As conditions developed, there were very strong winds all through the summer and the hot and dry weather that was being experienced continued throughout the summer with no significant rain. The fires burned much more severely than they had in previous years or as had been witnessed so far that summer. We learned what "worst-case" conditions were really like and, as a consequence, the North Fork and Clover Mist Fires became much larger than our projections indicated. The Fan Fire, Mink Fire, Falls Fire, Red Fire, and Shoshone Fire behaved more closely to our projections with the exception that the Red Shoshone Fire burned across the southern edge of Yellowstone Lake, which we hadn't predicted.

It was soon clear that the problem with the projections was that the younger stages of development of the lodgepole pine carried crown fires very readily and crowning was not limited to the LP-3 and LP-4 fuel types.

By late August, so many strong-wind events had occurred and the fires were becoming so large that conditions rarely seen before were occurring routinely. The fires were burning at night, or well into the night, with high intensity. A research crew, brought down from the fire lab in Missoula, found that the moisture content of the fine fuels was dropping to 4 or 5 percent during the afternoons and holding to these low values until 10 or 12 o'clock at night. The humidity recovery at night was not enough to bring these fuels up above 10 or 11 percent, never reaching the moisture of extinction of 15 to 20 percent. At these parched conditions, the fires were able to burn around the clock.

By assuming the fires would spread by spotting and crowning, we were able to project the fires more accurately. The projections for the rest of the summer for the overhead team at the Area Command were used to show the probable fire growth in the event of further severe winds. These projections were used to assess strategy which, by the end of August, had to resort to protecting life and property in high value areas. Overall fire suppression along the hundreds of miles of fireline was beyond hope until the weather changed.

On the 6th and 7th of September when some of the most severe fire behavior occurred, the National Fire Danger Rating Indices all went into the critical range. The 10th of September was expected to produce the worst fire weather of the summer with sustained winds over 40 miles an hour and gusts to 60 and 70 miles an hour. On the 9th, the North Fork Fire spread dramatically to the north, reaching the Mammoth area during the night, but fortunately, on the 10th of September the strong winds that were expected were accompanied by moisture. It rained in the Old Faithful area, snowed along the north edge of the Park, and produced a general rise in humidity, the expected extreme fire weather with strong winds was sharply moderated, and the worst of the fire season was over.

The summer's activities showed a strong need for methods of assessing extreme fire behavior. Work in this area will be accelerated, using experience from the Yellowstone and other large fires. Three research areas have been identified for concentration:

(1) Investigate extreme fire behavior and develop methods for predicting occurrence, intensity, and spread rates,

(2) Develop a fire growth model to predict fire behavior of large fires, and

(3) Develop methods for training fire behavior analysts to predict extreme fire behavior.